PAG spring 2018 (18 June 2018, Congress Centre, Davos, Switzerland)

(PACEO) Melt Ponds Climatic Impact Study

Brief Plan of Arctic Sea-Ice Field Activities (Sea-Ice Buoys) in Summer 2018

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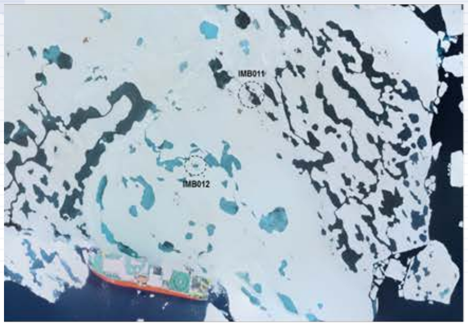
Sea ice activities of ice buoy deployments

- Since 2015, KOPRI has newly focused on deploying sea ice mass balance buoy with radiation (IMB-SR) through a melt pond, in collaboration with EU ICE-ARC programme.

2015



2016

2017

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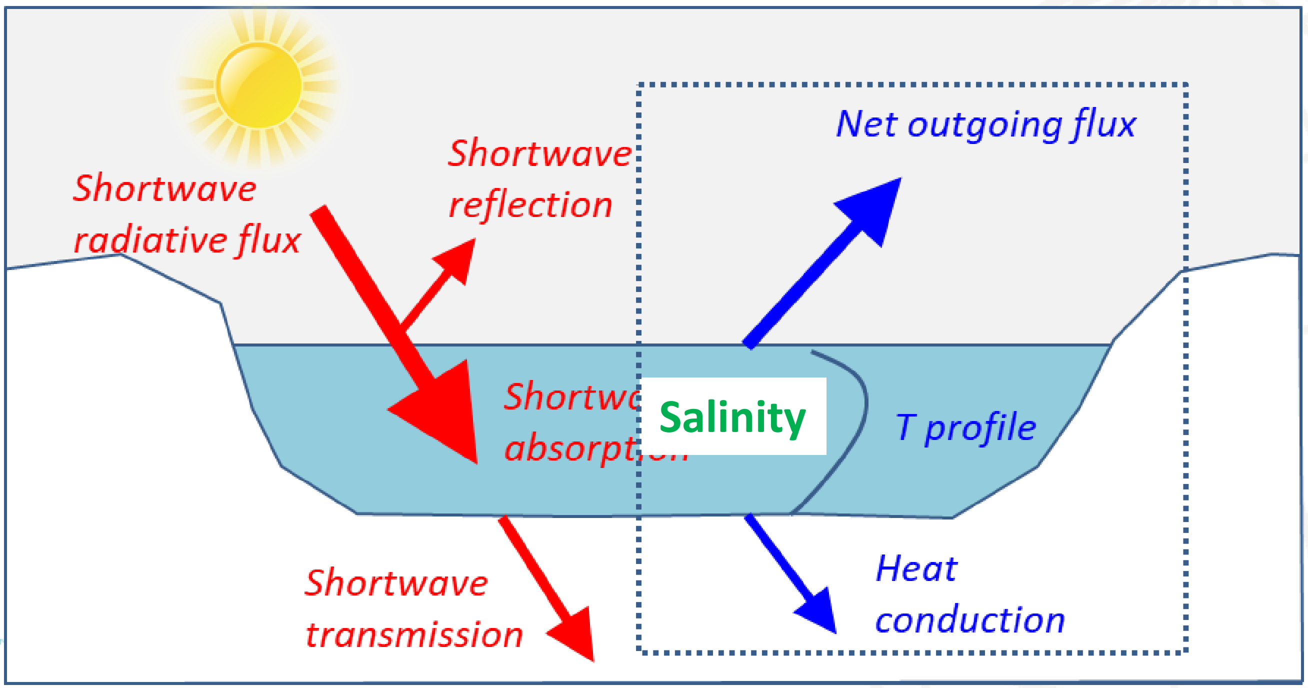
Working hypothesis

- Under changing dominant type of Arctic sea ice from MYI to FYI,
  - we expect increasing fraction of saline melt ponds.

- Could the change in pond salinity affect the heat transfer down to the ice?
  - Have we observed it? Do we understand the mechanism? Can current sea ice models deal with this issue?
    - Definitely, the answer to all questions is ‘No’.
  - Understanding this process could be of consequence in understanding melting acceleration over summer sea ice where numerous melt ponds form.



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Motivation

- **Treatment of melt ponds on sea ice in climate modeling**
  - Ebert and Curry (1993) – 'a bulk model'
    - The melt pond T is indistinguishable from the ice surface, due to *efficient mixing*.
    - Melt ponds only affect the surface albedo in the energy flux balance.
  - Taylor and Feltham (2004) – 'a layer thermodynamic model'
    - A simple two-stream RTM for shortwave, and turbulent heat fluxes in the pond interior
    - Internal heating by shortwave absorption can lead to convective instability inside a *fresh pond*.
    - The pond salinity is assumed to remain constant due to *mixing by turbulent convection*.
    - This model introduces the time dependency of the sensible heat stored within the pond and the effect of turbulent heat transport inside the pond.

The state-of-the-art sea ice model (e.g., LANL CICE5)

- … The formation, evolution and disappearance of melt ponds are governed by complex processes, including interactions with the existing snow layer, drainage rates through permeable sea ice, episodic refreezing and considerations of ice topography, making detailed melt pond modeling a daunting task. …
- … The ponds are assumed to consist of well-mixed, fresh water, and therefore their temperature is 0°C. …

- Elizabeth Hunke (Los Alamos National Lab.)

Motivation

- The treatment of the thermal characteristics of the pond interior have not been tested through comparison with *in situ* observations.
- Melt ponds can vary in salinity but the effect on heat transfer is not typically included in models.

Methods

- **Field work approach** – ‘diversification’
  - Simultaneous measurements of temporal thermal evolution of melt ponds with differing salinity under the same meteorological forcing
  - (Ideally) Instrumentation of multiple components (SW, LW, SH, LH, T, S, etc.)
  - Current limit: part of components (SW, T), limited observational (August)

- **Theoretical approach** – ‘simplification’
  - Assuming other conditions identical, the difference in sensible heat transfer to the ice below, due to differing salinity in a ‘statistical’ steady state
  - Current limit: Observational conditions are not exactly identical – basal ice albedo, pond geometry

- **Are those limitations limitation?**
  - Using linearized surface energy balance and focusing on the difference (freshwater versus saline), we can avoid some problematic points due to observational limitations
    - Not having all individual flux components is no longer critical.
    - Testing the sensitivity to varying environmental state (especially wind speeds)
      - A smart way of estimation of the scale of climatic impacts

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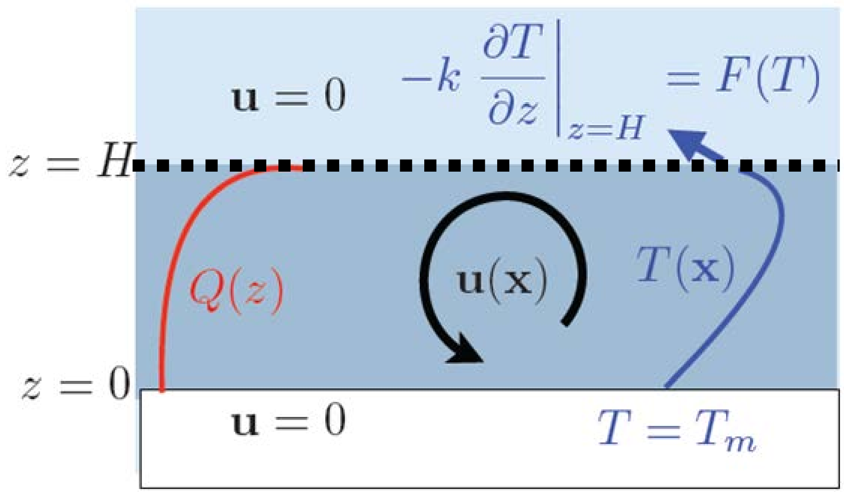
Theoretical approach

- Linearized version of surface energy flux balance (Hitchen and Wells, 2016)



$$k\frac{\partial T}{\partial z} = F_{LW} - \varepsilon\sigma T^4 - F_S - F_L \boxed{\approx\ -F_0 - \gamma(T - T_m)} \quad \text{at} \quad z = H$$

Sensible heat fluxes from the pond

F_{LW}: incoming longwave fluxes
$\varepsilon\sigma T^4$: longwave emissions
F_S, F_L: sensible & latent HFs

Final linearized version

F_0: net flux at T = T_m (melting temperature)
γ (≈ $\varepsilon\sigma 4T_m{}^3 + \rho_a c_a C_H U_{10}$) : net impact of deviations in T

(e.g.) ε=1, zero wind → γ = 4.6 W m^{-2} K^{-1} (longwave emission alone)
5 m s^{-1} wind → γ = 26 W m^{-2} K^{-1} (longwave emission & sensible HF)

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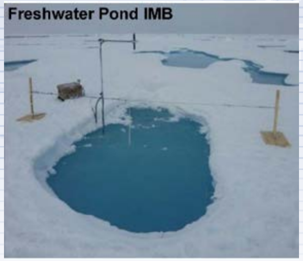
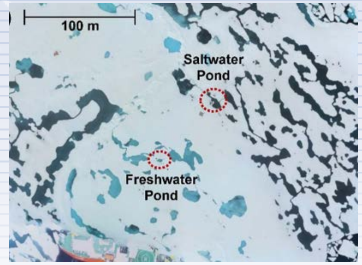
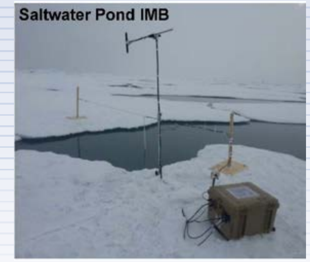
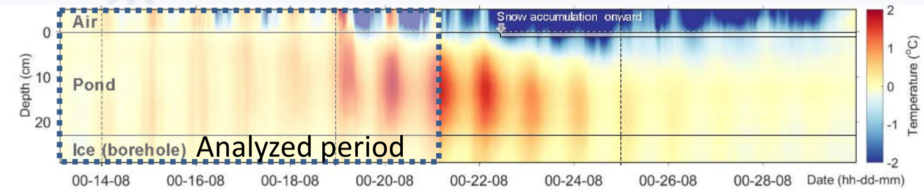
Flux estimation* (overall)

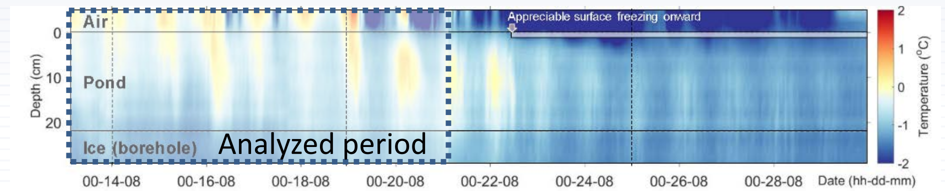
* Only holds for no ice lid condition











Observed variability of **pond surface temperature** (both ponds) **$-1.1\ ^\circ C < T_s < 0.9\ ^\circ C$**

Net flux perturbation (LW emission alone, $\gamma = 4.6$, compared to $T_s = 0\ ^\circ C$) **$-5\ W\ m^{-2} \le F' \le 4\ W\ m^{-2}$**

In a [statistically] steady state,

$$\boldsymbol{Q_0 H \approx \{F_0 + \gamma(T_s - T_m)\} + F_c}$$ (flux conducted down to the ice below)

→ Changing T_s directly correlates with a net change to F_c.

→ Any persistent model bias in T_s will lead to persistent bias in the predicted fluxes into the ice.

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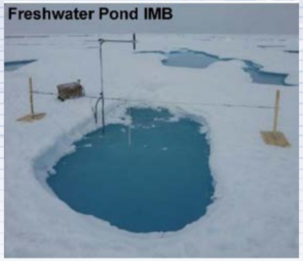
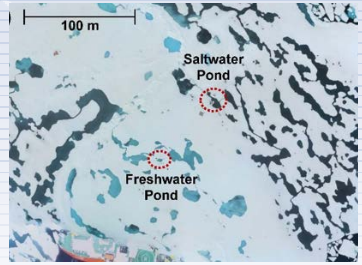
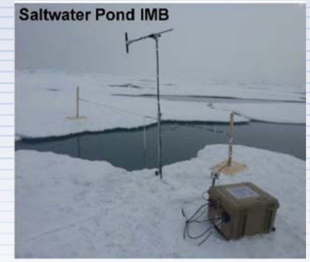
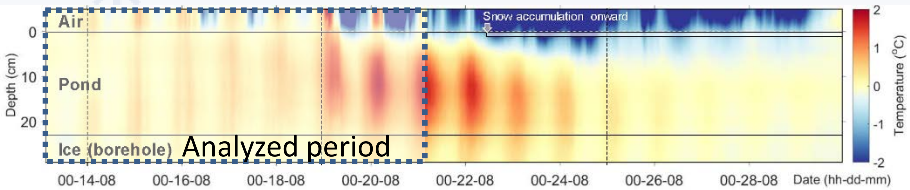
* Only holds for no ice lid condition

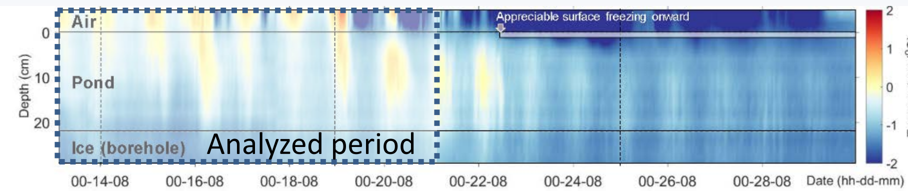
Flux estimation* (difference)











Estimation of the difference of time-averaged flux (ΔF_s: freshwater vs. saline)

(zero wind, longwave emission alone, $\gamma = 4.6$) $\Delta F_s \sim 2.2 \pm 0.3$ W m^{-2}

(5 m s^{-1} winds, $\gamma = 26$) $\Delta F_s \sim 12.5 \pm 1.8$ W m^{-2}

Estimation of the difference in the rate of change in pond heat storage (ΔF_{store}: freshwater vs. saline)

$$F_{store} = \rho c_p \int_{z_s}^{z_s+H} [T(z, t+\Delta t) - T(z,t)]dz/\Delta t$$

$\Delta F_{store} \sim 1.114 \pm 0.005$ W m^{-2}

Estimation of the additional heat flux down to the ice under saline ponds

(zero wind) **3.3** ± 0.3 W m^{-1} to (5 m s^{-1} winds) **13.6** ± 1.8 W m^{-1}

→ Faster melt under the saline pond (in otherwise identical conditions)

Implication for melt pond parameterization of sea-ice models

The state-of-the-art sea ice model (e.g., LANL CICE5)

- … The formation, evolution and disappearance of melt ponds are governed by complex processes, including interactions with the existing snow layer, drainage rates through permeable sea ice, episodic refreezing and considerations of ice topography, making detailed melt pond modeling a daunting task. …
- … The ponds are assumed to consist of well-mixed, fresh water, and therefore their temperature is 0°C. …

- Elizabeth Hunke (Los Alamos National Lab.)

- If fixed T_s = 0 °C as in current sea-ice models,
  - **(Freshwater pond)** generally T_s > 0 °C (no ice lid)
    → fixing T_s = 0 °C underestimates outgoing fluxes;
    hence almost persistent overestimates heat flux to the ice below.
  - **(Saline pond)** either overestimates or underestimates depending on the internal heating
    - Larger internal heating: $T_s \approx > 0$ °C
      → fixing T_s = 0 °C has an impact similar to the freshwater pond.
    - Smaller internal heating: $T_m < T_s < 0$ °C
      → fixing T_s = 0 °C overestimates outgoing fluxes;
      hence underestimates heat flux to the ice below.

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Conclusions

- The resulting variations of T_s perturb the pond energy budget significantly compared to the flux needed to thin the ice cover by 1 m per decade (Kwok & Untersteiner, 2011).
- Hence the internal redistribution and emission of heat from a melt pond augments the usual ice-albedo feedback, and is of potential climatological significance.
- This feedback from internal heat transfer is not fully accounted for in typical parameterizations of melt pond processes.
- The melt pond salinity and salt-stratification are key variables influencing the pond energy budget that are important to constrain in future observations and models.
- This is particularly important as saline ponds preferentially form on first year ice (Lee et al., 2011), and may increase in prominence as the Arctic transitions to a more seasonal ice cover.

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2018 sea ice field activity

- Cruise period: 4 to 24 August (from Nome to Barrow)

- Long ice camp: targeting 5 days north of the Chukchi Borderland (> 80N) (The other short one north of the East Siberian Sea)

- Physical, biological and chemical sampling

- Buoy deployments with EU Eco-Light programme (beyond physical buoys)
  - Ice mass balance buoy with radiation (IMB-R) by Bruncin
    - Joo-Hong Kim & Lovro Valcic et al.
  - Snow buoys (SB) by MetOcean
    - Julienne Stroeve et al.
  - Ice-tethered bio-optical buoys (ITBOB) & Spectral radiation buoy (SRB) by Bruncin
    - Lovro Valcic, Julienne Stroeve & Joo-Hong Kim
  - Zooplankton buoys (ZPB) by Bruncin
    - Lovro Valcic, Julienne Stroeve & Joo-Hong Kim

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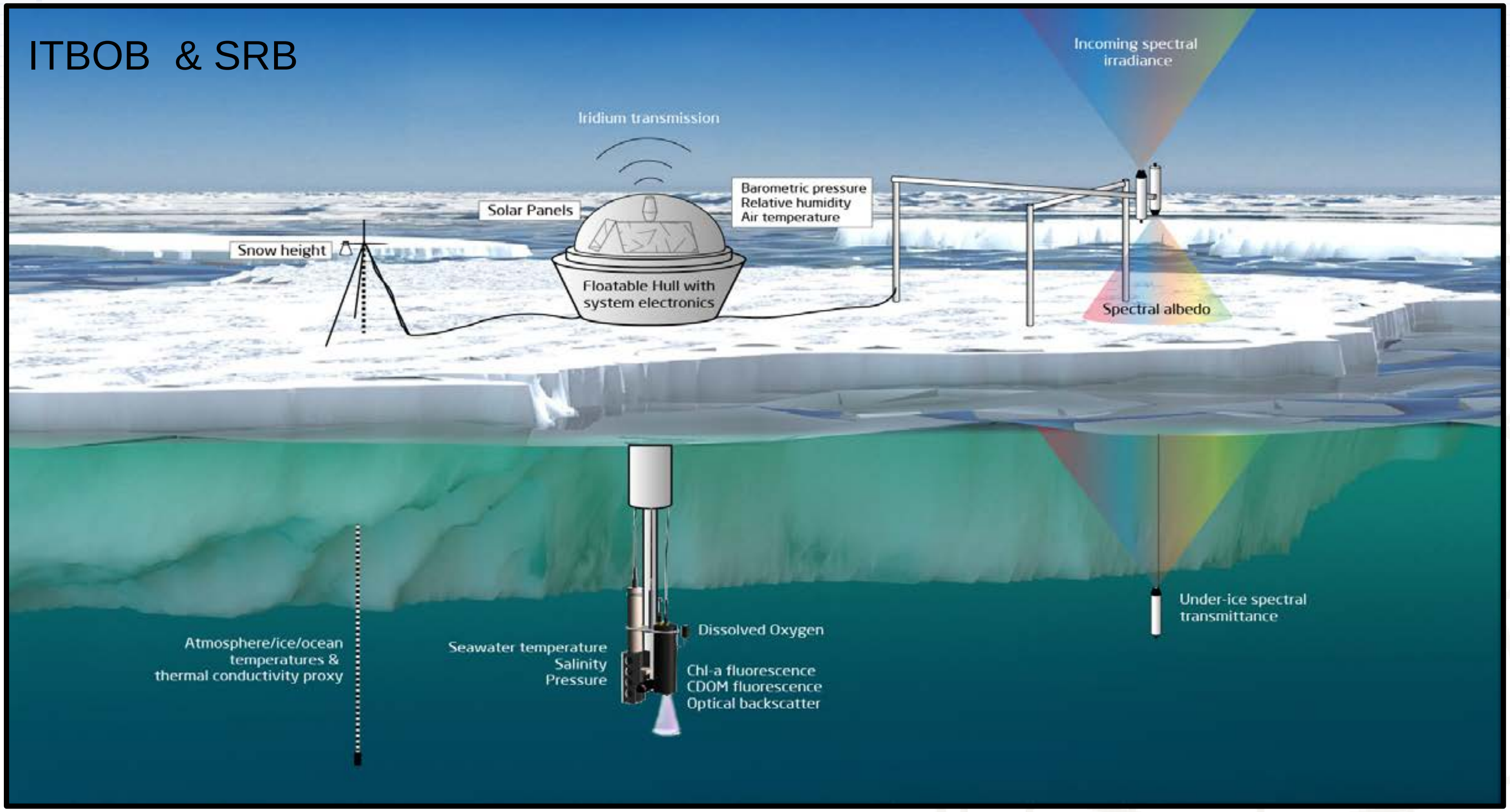
Eco-Light (Ecosystem functions controlled by sea ice and light in a changing Arctic)

(Working hypothesis) Changes in the timing and duration of primary production events, as well as changes in the grazing habits of zooplankton, mirror the variability in the light climate, which is driven by changes in the snow and sea ice regimes.



From Eco-Light programme summary

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Parameters

IMB-R

Parameter	frequency	Sensor Model
Atmospheric pressure (inside buoy)	Every hour	N/A
Incoming SW radiation (sky)	Every hour	Apogee SP-230
Reflected SW radiation (snow)	Every hour	Apogee SP-230
In pond SW radiation (incoming)	Every hour	Apogee SP-110
Under ice SW radiation (incoming)	Every hour	Apogee SP-110
GPS position	Every hour	N/A
IMB string (2 cm spacing)	Every hour	Bruchin
Salinity (under ice)	Every hour	Solumetrix
Salinity x3 (in pond)	Every hour	Solumetrix
WebCam	Every 6 hours	N/A

SB

Parameter	frequency	Sensor Model
GPS position	Every hour ??	??
Atmospheric pressure	Every hour ??	??
Air temperature	Every hour ??	??
sea surface temperature	Every hour ??	??
Snow depth x4	Every hour ??	??

ITBOB & SRB

Parameter	frequency	Sensor Model
GPS position	Every hour	Garmin 18x
Atmospheric pressure	Every hour	Bosch B280
Air temperature	Every hour	Honeywell
IMB string (2 cm spacing/ 4 m)	Every hour	Bruncin
TriOS Sensor (air: up)	Every hour	TriOS
TriOS Sensor (air: down)	Every hour	TriOS
TriOS Sensor (under ice: up)	Every hour	TriOS
ECO-triplet: backscatter	Every hour	Seabird
ECO-triplet: chl-a	Every hour	Seabird
ECO-triplet: CDOM fluorescence	Every hour ?	Seabird
Oxygen optode	Every hour	Aanderaa
Snow pinger	Every hour	robotics
Salinity (under ice)	Every hour	Solumetrix
SBE 37 CTD	Every hour	Seabird
WebCam	Every 6 hours	N/A

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Satellite data support for ice camp from US NIC (with ONR SODA)

Product	Frequency	Resolution	Provider	Responsible Person
Passive: Ice concentration (AMSR 2)	Daily	Footprint: 3125 m Swath: Pan Arctic (1450km)		
NIC: Ice Type Analysis (MY vs FY)	Weekly	Footprint: Dependent on available imagery. Swath: variable. As large or small as requested.	NIC	Walt Clark, William Walter
MODIS: Visible/IR image*	Daily	Footprint: vis:250m, IR:1000 m Swath: 2330km		
VIIRS: Visible/IR image*	Daily	Footprint: vis/IR: 375- 750 m Swath: 3040km		
SENTINEL 3: Visible/IR image*	Daily	Footprint: vis: 375 m, IR: 1000m Swath: Vis 1270km, IR: 1420 km		
SAR: RS-2; ScanSAR Wide** Single polarization	Daily	Footprint: 50-100 m Swath: 500 x 500 km		
SENTINEL 1: EW-WIDE SAR ** Single or Dual polarization	Daily??	Footprint: 50 m Swath: 400 x 400 km		

From SODA RSP (remote sensing plan) by Jeremy Wilkinson (BAS)

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Thank You